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# Critical design parameters for garages

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Professional paper

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## Critical design parameters for garages

The acceptability, usability, and economic success of garages depend on the quality of their design. Only minimum or even lower requirements are often applied. Problems most frequently encountered after the start of operation are: two spaces needed for one (bigger) car, scratches on cars and pillars, and long queues at entrance/exit. Main design parameters for garages are analysed in the paper: manoeuvrability in parking spaces and lanes, column grid, headroom, slopes and curves of ramps, garage floor slopes, and waiting time at garage entrance barriers.

### Key words:

garage, parking, design vehicle, parking space, queue length

Stručni rad

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## Kritični parametri projektiranja garaža

Prihvatljivost, iskoristivost i gospodarska uspješnost garaža ovisi o kvaliteti njihova projektiranja. Često se primjenjuju samo minimalni zahtjevi ili čak i manji. Nakon početka rada garaže najčešći problemi koji se pojavljuju su: dva parkirna mjesta potrebna za jedno (veće) vozilo, ogrebotine na vozilima i stupovima te dugi redovi čekanja na ulazu i/ili izlazu. U radu se analiziraju najvažniji parametri projektiranja u garažama: veličina parkirnog mjesta, mogućnost manevriranja na parkirnim mjestima i trakovima, raspored stupova, visina prolaza, nagibi i zavoji rampi, nagibi podova garaža te duljina reda čekanja na ulaznim rampama.

### Ključne riječi:

garaža, parkiranje, mjerodavno vozilo, parkirno mjesto, dužina reda čekanja

Fachbericht

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## Kritische Parameter im Entwurf von Garagen

Eignung, Effizienz und Wirtschaftlichkeit von Garagenanlagen ist von der Qualität des entsprechenden Entwurfsprozesses abhängig. Häufig werden nur die minimalen Anforderungen erfüllt oder nicht einmal erreicht. Nach Betriebsstart treten in Garagen oftmals folgende Probleme auf: Bedarf von zwei Parkplätzen für ein größeres Fahrzeug, Kratzer an den Fahrzeugen und Stützen, lange Wartezeiten am Eingang und/oder Ausgang. In der vorliegenden Arbeit werden die wichtigsten Parameter im Entwurf von Garagen analysiert: Größe des Parkplatzes, Manövrierbarkeit auf den Parkplätzen und Fahrspuren, Anordnung der Stützen, Durchfahrthöhe, Steigung und Kurven der Rampen, Bodenneigung, sowie Länge der Warteschlange an den Eingangsrampen.

### Schlüsselwörter:

Garage, Parken, Entwurfsfahrzeug, Parkplatz, Länge der Warteschlange

## 1. Introduction

Parking facilities can be open space one-level ground-surface facilities, with dedicated stripes for parking spaces and lanes, or they can be garage buildings above or under the ground surface. Garages are seldom stand-alone buildings, i.e. they are usually realized as parking levels integrated into a building in city centres, often below the ground level.

The demand for parking has a lot of variables. For city centres, the number of necessary parking spaces is largely dependent on the quality of the public transport system. Some big cities – at least in Germany – restrict realisation of new parking lots to a certain percentage if the project is well connected to a public transport system. Thus in the inner city of Frankfurt on the Main, Germany, it is only allowed to build ten percent of the parking lots one would normally have to build on a site situated outside the city [1]. Nevertheless, despite very good and very well used public transport services, a high demand still exists for good-quality parking lots, and this demand has to be satisfied to keep residents, customers, visitors, and employees staying and coming. As a rule of thumb, there are approximately 100 parking spaces per hectare in central business areas of big cities in Germany, out of which roughly 50 percent are public [2]. As an example, the map of the inner city of Frankfurt on the Main, Germany, shows both the main public transport stations and the public garages which provide approximately 11,700 public parking spaces in the city centre.



Figure 1. Public transport stations and garages in the centre of Frankfurt on the Main ([www.mainziel.de](http://www.mainziel.de))

## 2. Critical planning and design parameters

### 2.1. Design vehicle

Many older garages, but surprisingly some newly built garages as well, feature parking spaces and lanes that cause problems already when used by medium sized cars. Therefore, after deciding about the required number of parking spaces, the next important step in the planning process is to define a typical design vehicle for the actual garage project.

The design vehicle for a public garage should normally be a personal car which represents 85 % of vehicles currently

running in the region in which the garage is situated (e.g. there is no need to consider in central Europe provisions used in the United States where the design personal vehicle is 5,80 m long and 2,10 m wide (without mirrors), with an outer turning radius of 7.30 m [3]). Some countries choose the 80 % and/or 90 % (e.g. Austria) to decide on the size of design vehicles. Despite the widely talked-about small cars, 85 percent of vehicles in Germany – and it can be assumed for other central-European countries as well – have increased in size quite considerably over the past decades. Mainly the width (+8 cm) and the height (+16 cm) of vehicles have increased since 2000 (last data gathered before 2010). The data for Germany [4-8] are shown in the following Table 1.

Table 1. Development of design personal car size in Germany (85 % of cars)

Year	Length [m]	Width (without mirrors) [m]	Height [m]
1975. / 1991.	4,70	1,75	1,50
2000. / 2005.	4,74	1,76	1,51
2010. / 2011.	4,77	1,84	1,67

The resulting measurements for the 85 % design personal car for 2011 are shown in Figure 2 (typical cars approximately in the frame of the 85 % car are the Mercedes-C class, and the VW Passat 2010).

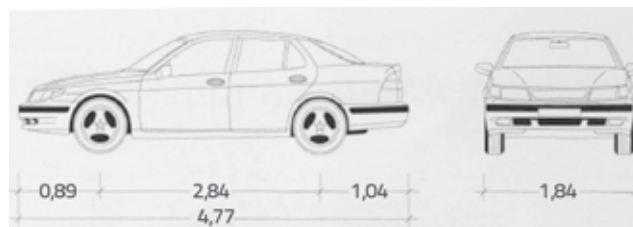


Figure 2. Design 85 % personal car in Germany 2010/11 [8]

This car size has been derived from all new personal cars including small and large ones, weighted with the number of registrations in 2010 in Germany. For users which have no clearly defined special needs, the design vehicle for a garage in central Europe – as an assumption based on the mentioned German data – would currently measure 1.84 m in width (without mirrors), and 4.77 m in length.

For special-purpose garages (e.g. a) garages in buildings with luxury apartments where more luxury cars and/or SUVs can be expected; b) garages or garage levels designated for small-sized vehicles like Smart), other design cars representing 85 % of a certain class should be chosen. Some of these classes are shown in Table 2.

A distinction between garages for long term and short term parking has not been considered because there is no reason to assume any difference in the mix of cars.

Table 2. Special car-classes in Germany (85 % car of the class 2010/11)

Car-class	Length [m]	Width (without mirrors) [m]	Height [m]
Ultra-small (e.g. Smart)	3,64	1,65	1,56
Upper (e.g. Mercedes S-class)	5,20	1,95	1,49
SUV (e.g. Porsche Cayenne)	4,77	1,91	1,75
Big utility vans (e.g. VW Multivan)	5,15	1,93	2,06

## 2.2. Size of parking spaces and lanes

Parking spaces and the adjacent area, i.e. the lanes along the parking spaces, must provide enough room to enable the above mentioned design vehicle to manoeuvre in and out of the parking space. In addition to the size of the car (width 1.84 m x length 4.77 m), there have to be enough reserves on all sides to allow for a secure, comfortable and careful driving. German guidelines for parking facilities ([7] chapter 4.2.1.6) consider 0,75 m between adjacent parked cars as comfortable, and 0,55 m as acceptable for the case of having the mirrors popped out and the doors opened at an acceptable angle. At the front and the rear of a parked car, the clearance of  $2 \times 0.15 \text{ m} = 0.30 \text{ m}$  is proposed. Together with the size of the design vehicle, and assuming that all cars are parked right in the middle of the parking spaces, the numerically deduced size of a parking space perpendicular to the lane would be:

**Length:**  $0.15 \text{ m clearance} + 4.77 \text{ m car} + 0.15 \text{ m clearance} = 5.07 \text{ m}$

**Width:**  $0.375 \text{ m clearance} + 1.84 \text{ m car} + 0.375 \text{ m clearance} = 2.59 \text{ m (comfortable)}$

**Width:**  $0.275 \text{ m clearance} + 1.84 \text{ m car} + 0.275 \text{ m clearance} = 2.39 \text{ m (acceptable)}$

As cars are not always parked in the centre of the parking space, and as drivers and passengers vary considerably in their behaviour when entering and leaving the car, it can rightly be assumed that the size of a parking lot perpendicular to the lane should be:

5.00 m x 2.50 m (length x width). This is parking space for the 85% design personal car.

Thus the proposed width of 2,50 m represents the median between "comfortable" and "acceptable" usage, and limits the floor-space consumption.

If upper class vehicles are chosen as benchmark for a garage project, the proposed size – taking into account Table 2 and allowing more space for door-opening – should be:

5.20 m x 2.70 m (length x width). This is parking lot for the 85% upper car-class.

If a parking space is marked directly along a wall, at least additional 0.20 m should be added to the width to enable most cars to move into the space from the front side, and not to have to turn around first and then enter the space from the rear side.

Lanes along parking spaces should allow for a secure slow driving along and moving into and out of the spaces. To enable entering a parking space of a certain width from a lane of a certain width, the necessary space for turning curves of cars, the column grid of the garage, and the angle at which individual spaces are aligned to the lane, have to be considered (see Figure 3).

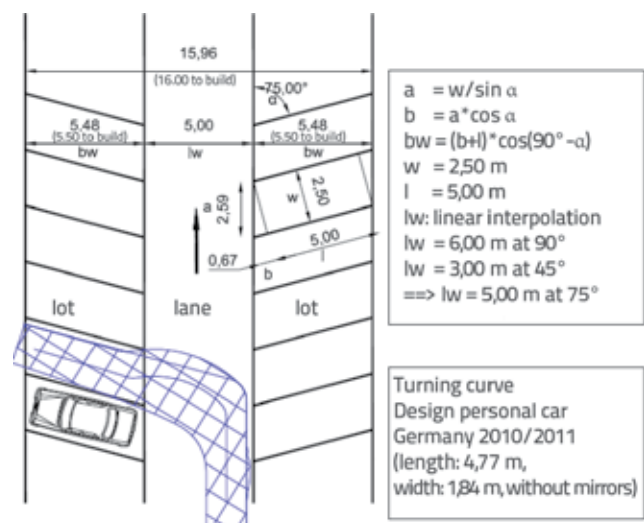


Figure 3. Geometry of parking spaces and lane (here spaces are aligned at 75°)

Some regulations still allow lanes 5,50 m in width, which is too narrow for present day car sizes, as the above mentioned numerically necessary length of a perpendicular parking space is already 5,07 m for the design personal car, out of which 5,00 m are marked as bay, overlapping already 0,07 m into the lane.



Figure 4. Parking spaces and lane with cars overlapping into the lane

If the construction system of a garage is not an open spaced facility without columns, the necessary space for columns, walls, insulation, and technical installations, has to be added to the measurements of parking spaces and lanes, as shown in Figure 3. As many garages are formed in underground levels of residential or office buildings, the construction grid of the building has to be adjusted to the grid of the garage. A good example with a quadratic grid of 8.10 m, i.e. 5 x 1.35 m, which is a common module in architecture, is shown in Figure 5.



Figure 5. Example of a column grid for buildings with underground garage level(s). Realized: Opernturm garage, Frankfurt on the Main, 2010

### 2.3. Headroom

A sufficient garage headroom has to be properly defined for ramps and parking levels. At the entrance, an appropriate sign has to show the allowed maximum height for entering vehicles (in addition, a hanging rod should warn if a car height is excessive). The usual displayed height is currently 2.00 m. Newer data show that the height of cars has increased considerably (see Tables 1 and 2). If it can be anticipated that a garage will frequently be used by SUVs and/or cars with roof tops, railings, and sport facilities, the allowed car entering height should be no less than 2.10 m.

As there are legally permitted tolerances between planned measures and actually realised measures (from at least 0.02 m up to 0.05 m, depending on national regulations and the local construction practice), these tolerances should also be taken into account. In addition, actual height of a car can differ from the height printed in the car's papers (due to e.g. tire pressure, suspension). Therefore as a sum of tolerances at flat garage levels, at least 0.10 m should be added to the height displayed at the entrance (e.g. entrance sign height of 2.00 m leads to planned headroom of 2.10 m at flat level). More headroom has to be provided along sloped ramps (see Figure 6): +10 cm along the ramp (altogether 2.15 m, if 2.00 m is displayed). Where the slope changes by 8 % or more (e.g. from 15 % sloped ramp to 0 % at the flat garage level) +20 cm at slope-changing points and 1.50 m along both sides of these points have to be considered (altogether 2.25 m, if 2.00 m is displayed).

An additional headroom might be necessary, if the garage level is sloped for drainage (cleaning water, thawing ice and snow),

and to avoid uncontrolled puddles and resulting danger of chloride impact. The necessary slope has to be at least 2 % to ensure that the water flows in the right direction, and having in mind construction tolerances.

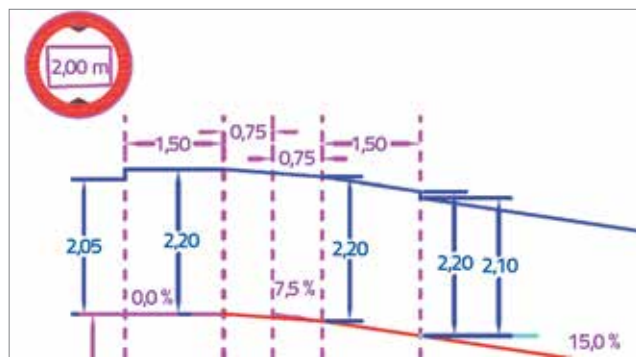
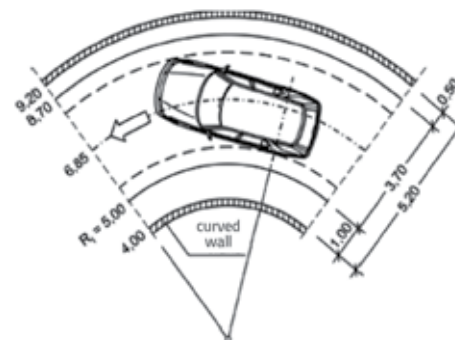


Figure 6. Example for calculating headroom along a garage ramp (5 cm construction tolerance not included!)

### 2.4. Ramps

Ramps are garage elements enabling cars to move between parking levels. For the longitudinal section design, a ramp should not exceed 15% (in the middle of the respective lane), but short ramps inside a garage may be sloped up to 20 %. If the slope difference is more than  $\Delta s = 8 \%$ , a flatter section with 7.5 % for 1.5 m (0.75 + 0.75) at the top, and 2.5 m (1.25 x 1.25) at the foot of the ramp, has proven to be sufficient to avoid car damage (e.g. see Figure 6) [7].

The horizontal design of a ramp has to comply with the turning curves of the chosen design vehicle, with additional clearance to allow for comfortable and secure driving. The lane width of linear ramps should be no less than 2.75 m, while an additional clearance of 25 cm should be provided on both sides. Curved ramps must have a radius of at least 5.00 m at the inner lane boundary, with at least 3.50 m in lane width. An additional clearance of at least 25 cm should be provided on both sides. Some sources require 3.70 m lane plus 30 ... 50 cm clearance for a more comfortable driving [7, 9]. Dimensions proposed in [7] are shown in Figure 7.



$R_i$ [m]	5,0	6,0	7,0	8,0	9,0	10,0	12,0	14,0	16,0	18,0	20,0
f [m]	3,70	3,60	3,50	3,45	3,40	3,35	3,25	3,15	3,10	3,05	3,00

Figure 7. Measures proposed for spiral ramps [7]



Figure 8 shows a spiral ramp with (nearly) minimum size: inner radius 4.75 m, outer radius 8.75 m (= lane width 3.50 m + 2 x 0.25 m). This ramp serves a 4-level underground garage with 1.400 parking spaces, with no known complaints.



Figure 8. Spiral ramp 4 m in width, inner radius: 4,75 m (My Zeil, Frankfurt)

## 2.5. Queue length at barriers

The entrance and exit barriers can lead to considerable queue lengths, and these can disturb traffic on the adjacent street and/or the traffic flow within the garage. German guidelines for garage facilities ([7], annex K)

introduce a queue length assessment method based on known and proven capacity of certain control devices. Certain parameters such as the location, user groups and kind of chosen control devices are included. Based on location, user characteristics and time distribution the trip generation has to be calculated (data "traffic flow entering garage" in Figure 9). The expected queue length is assumed based on empirical data and computer simulation results. Summarizing and compressing the data, Figure 9 shows the expected queue length (number of personal cars, each car can be assumed to be 6 m long including the distance between cars) for a known volume of the entering traffic flow. The results have proven to be quite reliable, leaning a bit to the safe side if tried with real traffic evaluations [10, 11].

## 3. Conclusion

The design of a modern garage building can guarantee a good usability by providing parking spaces, lanes and ramps which fulfil the needs for parking a typical personal car. Such a car has grown in size over the past decades, with the technical guidelines staying mostly behind. Therefore today's parking facilities should have parking spaces that are at least 2.50 m wide, while lane width should be at least 6.00 m. Other important design parameters are: headroom (at least 2.00 m for car height), ramp dimensions (slope, width, flattening), and queue length at barriers.

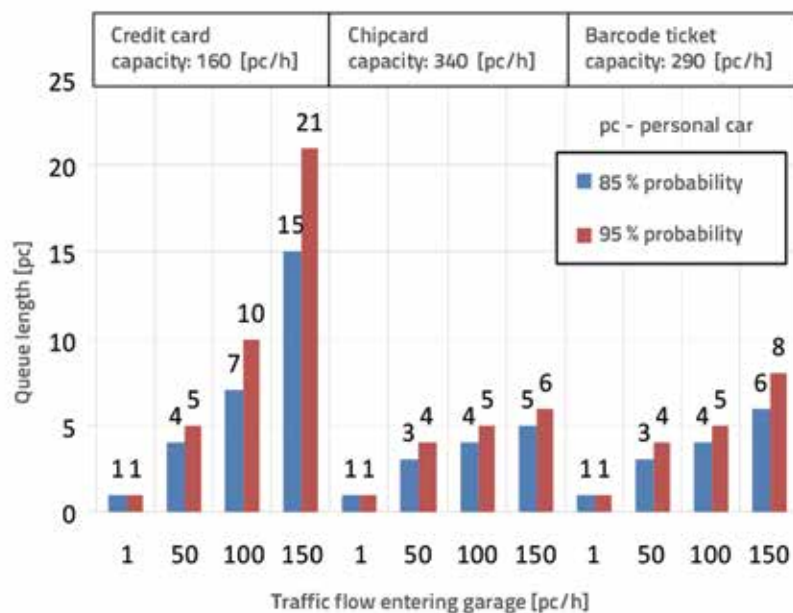


Figure 9. Queue length assumption [7, 10]

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